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<b>14. ABSTRACT</b> New fixed focal length transducers were developed for the INSS (Integrated Navigation and Sensor System) diver held sonar which allows a VSW diver to obtain a very high resolution sonar image (with approximately 1 in. by 1 in. resolution at a range of 15 ft) and to obtain a lower resolution image of buried targets. With these new focused transducers (which will replace the existing INSS transducer) the diver should obtain identification quality sonar image of mines while at a safe standoff distance that corresponds to the focal length of the array. A second characteristic of these new transducers is that they will be sufficiently broadband to allow operation at very low frequencies. This will allow the sonar sound to propagate through the bottom and thereby allow lower resolution imaging of buried targets. The high resolution imaging target identification capability will provide a significant reduction in risk to the VSW MCM divers who currently have to swim up and see/touch mine-like targets for identification in turbid water					
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# **Very High Resolution Imaging Diver Held Sonar Final Technical Report**

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## **LONG-TERM GOAL**

The long-term goal had two parts. The first was to evaluate the feasibility and usefulness of a high resolution fixed focus single beam manually scanned sonar. And, the second was to evaluate the buried target detection capabilities obtainable with the same design. If these capabilities prove valuable they can be incorporated into the following three systems:

- The diver held Integrated Navigation and Sonar System (INSS) that is being used by the VSW-MCM detachment.
- The Under Water Imaging System (UIS) under development for EOD
- The Hydrographic Littoral Mapping Device under development for NSW

## **OBJECTIVES**

The objective is to develop new transducers and lenses with fixed focal lengths for the INSS (Integrated Navigation and Sensor System) diver held sonar. The largest of these will allow a VSW diver to obtain a very high-resolution sonar image (with approximately 1" by 1" resolution at a range of 15 feet) and to obtain lower resolution images of buried targets. The current resolution with the existing INSS transducer is 1" by 6" at 15 feet range (which is really only sufficient for gross imaging of target features) and the current INSS sonar provides no buried mine detection capability. With these new focused transducers (which will replace the existing INSS transducer), and/or lenses (which will simply be placed over the transducer) the diver can obtain identification quality sonar images of mines while at a safe standoff distance that corresponds to the focal length of the transducer / lens. This will eliminate the need (in most cases) for the diver to see / touch the mine for target identification. With the proposed resolution, features such as bolt patterns, lifting eyes, and arming plates should be visible. A second characteristic of these new transducers is that they will be sufficiently broad band to allow operation at very low frequencies. This lower frequency operation will allow the sonar sound to propagate through the bottom and thereby allow lower resolution imaging of buried targets.

## **APPROACH**

This effort can be divided into 5 portions, all of which will be overseen by Dr. Keith Lent.

The first portion of this project was the design and construction of a test transducer and three lenses. The transducer will be constructed from a 1-3 composite piezo-ceramic material using standard transducer construction techniques. This transducer's aperture is 24". The transducer has a focal length of 15 feet. The three lenses are simple cylindrical lenses machined out of a flat sheet of acrylic.

Mechanical engineers and technicians here have done the detailed mechanical design and construction of these transducers.

The second portion of this project consisted of the modification and testing of the software in the INSS system to support the high resolution and buried target imaging. This software is written on a standard notebook computer and then downloaded into an INSS system for testing.

The third portion of this program was the test and evaluation of tradeoffs between the various adjustable parameters in the transducers in a working INSS system. These tests were done by evaluating the sonars performance with the various parameter configurations in ARL:UT test tanks, the Lake Travis Test Station facility. Tests / evaluations were conducted using VSW-MCM, EOD and NSW divers. They contributed valuable feedback on the acceptability / usability of these transducers for their various missions. The goal of this portion was to determine the optimal parameters for the final design of the transducer and/or lens. During these tests both proud and buried mines as well as other test targets were be used.

The forth portion of this project consisted of the construction of a final transducer and lens with the optimal size and focal length parameters determined during the previous evaluation.

The fifth portion will consisted of verification and demonstration of the final design in a realistic environment using VSW MCM detachment divers.

## **WORK COMPLETED**

The design and construction of three lenses and one test transducer has been completed. The three lenses are each 8 inches wide by 2 inches tall and are designed to be placed in front of the existing INSS transducer. They are designed to focus at 5', 10' and 15' and should provide better than 1"x1", 1"x2" and 1"x3" resolutions respectively. The test transducer is a fixed focus transducer with a 24" aperture focused at 15'. It provides better than 1"x1" resolution.

The software for a INSS sonar has been modified to provide a zoom window in which the high resolution imaging can be viewed. It has also been modified to provide a low frequency mode of operation for detecting/imaging buried targets.

The initial in water tests of the lenses and test transducer have been completed. Sonar images have been recorded of test targets and mine simulators. Also, images have been recorded of test targets both proud and buried in sand to ~1" depth.

Divers from the VSW-MCM detachment, EOD and NSW operated and evaluated this prototype hardware in early October 2000. They provided feedback to help determine the optimal choice of design parameters for the final design. This has been determined to be a 16" aperture unfocused array with a removable (flip up/down) lens focused at 15 feet. This array was chosen because it is small enough to fit within the current width of the INSS sonar design (handle to handle) and large enough to provide high resolution imaging at 15 foot range. Also, because it will incorporate a flip up/down lens, only one transducer is necessary for both long range target search and short range focused target imaging.

The final transducer and lens has been built and tested by the VSW-MCM divers in Sand Diego Bay. They have evaluated the design and provided recommendations for its inclusion into future INSS and UIS systems.

## **RESULTS**

A 24" aperture, 15' focal length test transducer and 3 lenses have been constructed and tested and evaluated. The results have been very successful. The achieved focal resolution matched the theoretically predicted resolution, and no significant lens imperfections or impedance mismatch related distortions were seen. What this means is that when the lens designed to focus at 5' is used the resulting image resolution is slightly better than 1"x1". This means that 1/8" bolt heads placed 1" apart

can be resolved. A test target consisting of a 17"x14" aluminum plate was constructed to verify this resolution. It has a number of bolts placed at 3" , 2" and 1" spacings. It also has a 6 bolt circular pattern to simulate an electronics housing cap that could be similar to a mine/bomb access plate. A photograph of this target, along with a brick and a string of Ping-Pong balls is shown in the Figure #1. Figure #2 shows an INSS sonar image of the same three targets with the zoom mode enabled, but without any lens or focusing. The zoom mode window, which appears in the lower right corner of the display, is an enlarged view of the sonar data at the center of the main display. Note; at the far edge of the image the wall of the test tank is also visible. This image shows the resolution of the existing INSS sonar. The plate and brick and Ping-Pong ball string are recognizable as separate objects but they are clearly blurred out. The INSS resolution (unfocused) is about (1"x8"). Notice that the brick has been smeared out horizontally to appear almost square. Figure #3 shows the exact same scene with the only change being that a lens has been snapped on to the front of the INSS sonar. The lens is designed to focus at 5'. As before the plate and brick are enlarged in the zoom window, but in this image the bolts have become visible and the edges of the brick and the plate are much sharper. Figure 34 shows an even greater zoomed (enlarged) image of the same plate (note the ping pong ball string has been moved). In this image only the lower half of the plate is seen in the zoom window and the brightness has been decreased from the previous image. All of the bolts even those 1" apart are resolvable.

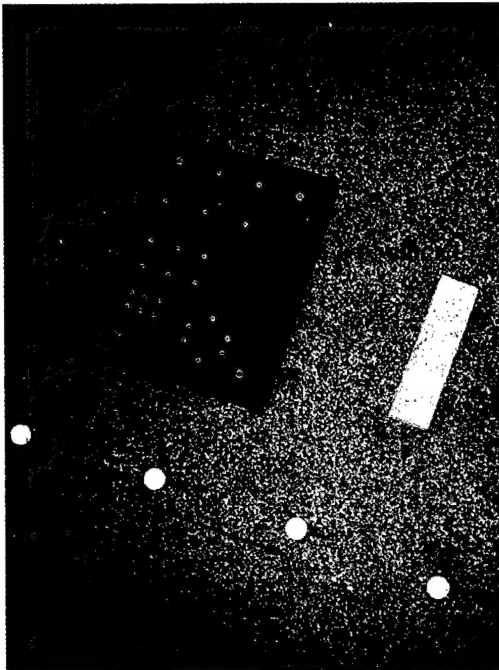


Figure #1: Photo of Test targets

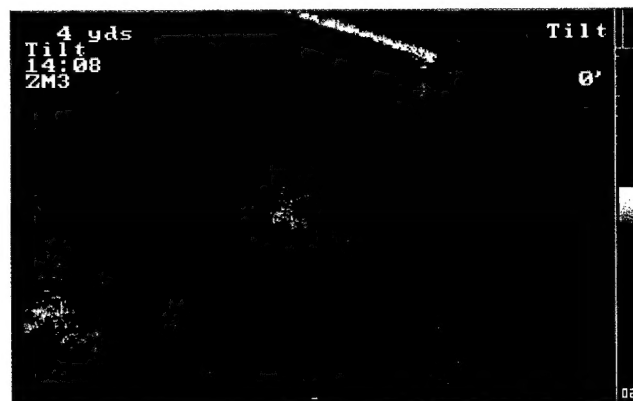


Figure #2: Unmodified INSS sonar image of test targets

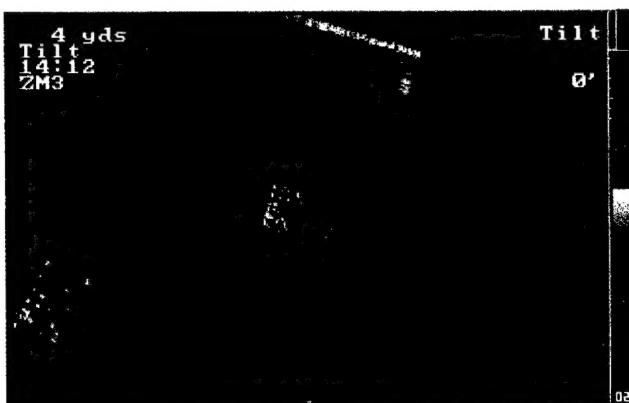


Figure #3: Image with 5' focus lenses

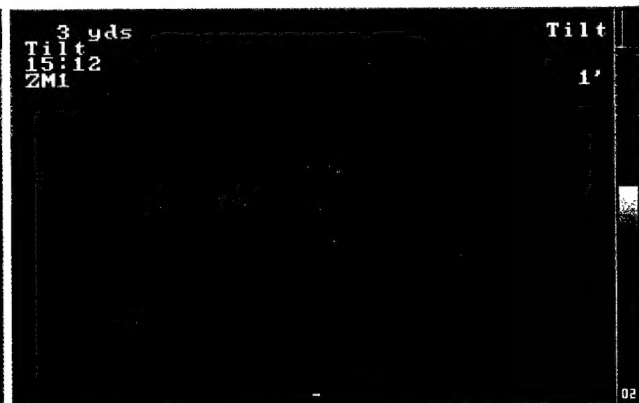


Figure #4: Greater zoom image w/ 5' focus lens

Next tests were done with the 24" aperture fixed focused transducer, focused at 15'. Figure #5 shows a picture of the test target lying on a sandy bottom 15' away from the sonar. Figure #6 shows the sonar image obtained with the INSS sonar with this new transducer. All of the bolts can be resolved on the plate. This demonstrates that the INSS sonar combined with this transducer has at least 1"x1" resolution at 15'.



Figure #5: Photo of test target on sand

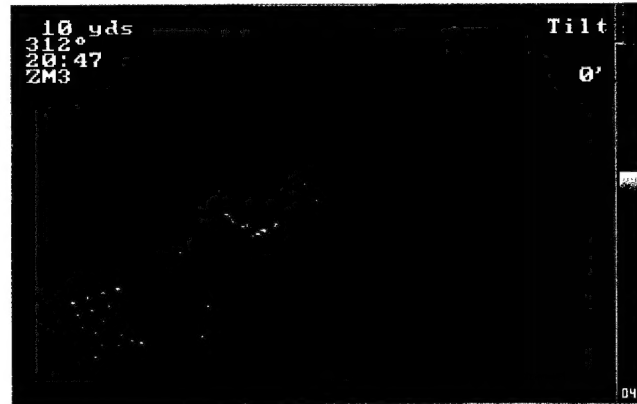


Figure #6: Sonar image using 15' fixed focus transducer

Tests have also begun which consist of imaging mine simulators. Figure #7 shows a photograph taken of a mine simulator that was placed on a sandy bottom. Figure #8 shows the sonar image of this target obtained with the fixed focal length transducer at 15' from the sonar. The rod that protrudes from the top of the mine is approximately 1" in diameter, and the rod, ball, mount and base plate are all clearly visible. The base plate is approximately a 2' x 2' square. In this particular sonar image the brightness has been turned up so that the shadow cast on the sandy bottom is visible.



Figure #7: Mine simulator on sandy bottom



Figure #8: Sonar image of mine at 15' range

Tests with buried targets have also been conducted. The first test done consisted of imaging a row of ping pong balls (test targets) in normal and buried (low frequency) modes. Four of the Ping-Pong balls were not buried, 1 was partially buried and 1 was about 1" below the bottom buried in clean sand. At the normal sonar operating frequency only the non-buried Ping-Pong balls could be detected. But, using the low frequency mode of operation all of the Ping-Pong balls were detected. The echo level from the buried ball was about 7dB lower than the rest. These test targets were used to help select the optimal frequencies for buried mode operation.

The second test consisted of imaging a buried test target (5 corner reflectors) in a controlled sandy environment at Lake Travis. The VSW MSM divers used the INSS sonar with the "low frequency buried mode" software to dive on and locate this buried object. The test target was



completely buried in the sand and with only 30 minutes instruction the divers were able to consistently locate this target. The key acoustic phenomenon which must be understood and applied to find buried targets is the critical angle. Below this angle almost no sound penetrates into the bottom. For sandy bottoms this angle is about 30 degrees. This means that the diver/sonar must be at least 5 feet above the bottom to search for buried target up to ten feet away. In other words the diver must stand up when searching for buried targets. If the diver operates the sonar while lying on the bottom (the normal VSW MCM configuration) then no buried targets can be seen.

A third test has subsequently been conducted with a buried mine simulator and ARL:UT divers. The completely buried mine was detected above the critical angle. The resolution of the target was (as expected) significantly poorer than in the normal high frequency mode. The target in fact appears as a bright blob without distinguishing features. However, it was clearly distinguishable from the sand and the ARL:UT diver could easily locate and home in on the target.

The final 16" transducer with a single 15' focal length lens has been built and tested by VSW-MCM detachment divers in San Diego Bay April 1-5 2002. The final system was evaluated by three VSW MCM Det personnel: (Ban Joseph, Mark Hawes, and Mike Coleman). Two of these people were Force Recon Marine Divers and one was a Navy SEAL. All three had extensive dive experience with the INSS system. Valuable feedback was obtained from each of these personnel after they were trained and dove the system. Their feedback was used to recommend future inclusion of this capability in the INSS and UIS systems to the program office. Of particular value were the following recommendations and comments by VSW Personnel: "Good for confirming Mine types, feasible for VSW MCM Missions", "The Zoom (high resolution) window should automatically come on at the 10 yard scale and not be a separate mode", and "The Zoom box cursor should stay visible during scanning to help guide diver movement". This feedback is very valuable and will be used by ARL:UT to improve future implementations of this system.

## **IMPACT/APPLICATION**

The high resolution imaging target identification capability will provide a significant reduction in risk to the VSW MCM divers who currently have to swim up and see / touch mine like targets for identification in turbid water. The buried target detection capability is also beneficially to the these divers and EOD divers who must locate and ID buried targets that have been found but not identified by marine mammal systems and/or larger low frequency mine hunting ship board sonars. Currently the only way for a diver to confirm the presence of a buried target is by digging or probing with sticks into the bottom. However, since the marine mammal marks and/or large ship sonar marks are often only accurate to a few yards, it is a tedious and often dangerous process to find and confirm a buried mine mark. It is important to note that this capability will be valuable even though the buried target detection will likely work well only at short ranges i.e. for detecting buried targets within ~10 to 20 yards.

## **TRANSITIONS**

The software developed in this program is already being transitioned into the INSS, UIS and HRLMD systems. This includes the zoom mode window and the buried - low frequency operating mode. Even without transducers or lenses these changes have been seen to provide additional value to the diver. The final 16" transducer with flip up/down lens has been evaluated and will likely transition into the UIS system in the 2003 /2004 time frame.

## **RELATED PROJECTS**

INSS, UIS and HRLMD are ongoing projects funded by PMS EOD, ONR and NSW to develop diver based underwater navigation and sonar systems for detecting, marking and relocating mines and other objects in the VSW and SW environment.

## **DISTRIBUTION LIST**

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